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The work supported by the grant NGL-47-004-033 and its supplements #1 and #2 has been completed. The final report contains the lists of the Ph.D. theses, publications, and talks given at professional meetings which are based on the research supported.

Besides these documented results, the grant has allowed the Physics Department to gather and maintain an active research group in medium energy physics and has helped us greatly in improving the graduate programs in this area. It has also provided the basis on which this group can continue to work in the same field with the new generation of accelerator, meson factories.

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Ph.D. Theses:

T. R. Witten

"Single Proton Emission Following Positive Pion  
Capture in Carbon" 1969.

W.-C. Lam

"Neutrons from Radiative Capture of Pions by Complex  
Nuclei" 1970.

D. A. Bryman

" Search for  $\mu^- + \text{Cu} \rightarrow e^+ + \text{Co}$ " 1972.

Publications in Open Literature:

"Elastic Scattering of 600 MeV protons by  $^4\text{He}$ ," E. T. Boschitz, W. K. Roberts, J. S. Vincent, K. Gotow, P. C. Gugelot, C. P. Perdrisat and L. W. Swenson, Phys. Rev. Letters 20, 1116 (1968).

"Single Proton Emission Following Positive Pion Absorption in Carbon," T. R. Witten, M. Blecher and K. Gotow, Phys. Rev. 174, 1166 (1968).

"Polarization in Proton- $^4\text{He}$  Scattering at 540 MeV," K. Gotow, E. T. Boschitz, W. K. Roberts, J. S. Vincent, P. C. Gugelot, C. F. Perdrisat and L. W. Swenson, Phys. Rev. Letters 21, 1816, (1968).

"The  $3d \rightarrow 2p$  Pionic Transition in  $^{58}\text{Ni}$  and  $^{60}\text{Ni}$ ," Jenkins, Powers and Miller, Phys. Rev. 185, 1508 (1969).

"The  $2p \rightarrow 1s$  Pionic Transition," Anderson, Jenkins and Powers, Phys. Rev. 188, 9 (1969).

"Rare Mode Pion Absorption," K. Gotow, Proceeding of the Third International Conference on High Energy Physics and Nuclear Structure, (1969).

"Neutron-Matter Radii from an Analysis of Pionic Atoms," Anderson, Jenkins and Powers, Phys. Rev. Letters 2, 71 (1970).

"The  $5g \rightarrow 4f$  Pionic Transition in  $^{232}\text{Th}$  and  $^{238}\text{U}$ ," Jenkins, Powers and Kunselman, Phys. Rev. C Third Series, 2050 (1970).

"Elastic Scattering of 580 MeV Protons from  $^3\text{He}$ ," M. Blecher, K. Gotow, E. T. Boschitz, W. K. Roberts, J. S. Vincent, P. C. Gugelot, C. F. Perdrisat, Phys. Rev. Letters 24, 20 (1970).

"Large Angle p-d Scattering at 580 MeV," J. Vincent, W. K. Roberts, E. T. Boschitz, L. S. Kisslinger, K. Gotow, P. C. Gugelot, C. F. Perdrisat, L. W. Swenson and J. R. Priest, Phys. Rev. Letters 24, 236 (1970).

"The  $4f \rightarrow 3d$  Pionic Transition in  $^{138}\text{Ba}$ ,  $^{140}\text{Ce}$  and  $^{142}\text{Ce}$ ," Jenkins, Powers and Kunselman, Phys. Rev. C2, 429 (1970).

"Muonic Interactions in  $^{66}\text{Zn}$  and  $^{68}\text{Zn}$ ," Jenkins, Powers and Kunselman, Phys. Rev. C2, 458 (1970).

"2s Atomic Levels in Muonic  $^{140}\text{Ce}$ ," Jenkins, Powers, Martin, Miller, Welsh and Kunselman, Phys. Letters 32B, 267 (1970).

"Electric Quadrupole Transitions in  $^{208}\text{Pb}$ ," Jenkins, Powers, Martin, Miller and Welsh, Phys. Rev. Letters 25, 1406 (1970).

"2S Atomic Level in Muonic  $^{208}\text{Pb}$ ," Jenkins, Powers, Martin, Miller and Welsh, Nuclear Physics A175, 73 (1971).

"A Large Volume Proportional Counter," Jenkins, Nuclear Instruments and Methods 93, 169 (1971).

"Neutrons from Radiative Pion Capture by  $^{12}\text{C}$ ," W. C. Lam, B. MacDonald, W. P. Trower, D. K. Anderson, K. Gotow, Phys. Rev. Letters 28, 108 (1972).

"Search for the Reaction  $\mu^- \text{Cu} \rightarrow e^+ \text{Co}$ ," D. Bryman, M. Blecher, K. Gotow, R. J. Powers, Phys. Rev. Letters 28, 1469 (1972).

"Elastic Scattering of 600 MeV Protons from H, D,  $^3\text{He}$ , and  $^4\text{He}$ ," E. T. Boschitz, W. K. Roberts, J. S. Vincent, M. Blecher, K. Gotow, P. C. Gugelot, C. F. Perdrisat, L. W. Swenson, and J. P. Priest, Phys. Rev. C 6, 457 (1972).

"Elastic Scattering of Negative Pions from  $^{16}\text{O}$  in the Region of the (3,3) Resonance," R. W. Bercaw, J. S. Vincent, E. T. Boschitz, M. Blecher, K. Gotow, D. K. Anderson, R. Kerns, R. Minehart, K. Ziolk, and R. Johnson, Phys. Rev. Letters 29, 1031 (1972).

#### Textbook Articles:

Muonic and Hadronic Atoms, D. K. Anderson and D. A. Jenkins, Chapter V.A. of Nuclear Spectroscopy, Ed. by J. Cerny, Academic Press. (To be published).

Talks Given at Professional Meetings:

"Measurement of Pionic X Rays in Nickel," Jenkins, Powers, and Miller, Bull. Am. Physical Society 13, 1726 (1968).

"Elastic Scattering and Polarization of 600 MeV Protons by  $^4\text{He}$ ," E. T. Boschitz, W. K. Roberts, J. S. Vincent, K. Gotow, P. C. Gugelot, C. F. Perdrisat and L. W. Swenson, Bull. Am. Phys. Soc. 13, 679 (1968).

"Neutrons from Radiative Pion Capture in  $^{12}\text{C}$ ," W. C. Lam, K. Gotow, B. MacDonald and W. P. Trower, Bull. Am. Phys. Soc. 13, 715 (1968).

"P-D Polarization and Elastic Scattering Near 550 MeV," J. S. Vincent, E. T. Boschitz, W. K. Roberts, K. Gotow, P. C. Gugelot, C. F. Perdrisat and L. W. Swenson, Bull. Am. Phys. Soc. 13, 877 (1968).

"Elastic Scattering of 600 MeV Protons from  $\text{He}^3$ ," E. T. Boschitz, W. K. Roberts, J. S. Vincent, M. Blecher, K. Gotow, P. C. Gugelot and C. F. Perdrisat, Bull. Am. Phys. Soc. 13, (1968).

"Pionic Interactions in 1s Atomic Orbits," Powers, Anderson and Jenkins, Bull. Am. Physical Society 14, 88 (1969).

"Neutrons from Radiative Pion Capture in Calcium," W.-C. Lam, K. Gotow, B. MacDonald and W. P. Trower, Bull. Am. Phys. Soc. 14, (1969).

"Rare Mode Pion Absorption," K. Gotow. Invited talk given at the Third International Conference on High Energy Physics and Nuclear Structure, Columbia University, New York, New York, September 1969.

"Strong Interaction Effects in  $\pi$ -Mesic Atoms," D. K. Anderson, Bull. Am. Phys. Soc. October (1969).

"Direct Neutron Emission from Radiation Pion and Muon Capture in Nuclei," D. K. Anderson, Bull. Am. Phys. Soc. 15, 596 (1970).

"Muonic X Rays in  $^{140}\text{Ce}$ ," Martin, Miller, Welsh, Jenkins, Powers and Kunselman, Bull. Am. Phys. Soc. 15, 558 (1970).

"Pionic Transitions in  $^{138}\text{Ba}$ ,  $^{140}\text{Ce}$ ,  $^{142}\text{Ce}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$ ," Jenkins, Powers and Kunselman, Bull. Am. Phys. Soc. 15, 560 (1970).

"Muonic X-Rays in  $^{208}\text{Pb}$ ," Jenkins, Powers, Martin, Miller and Welsh, Bull. Am. Phys. Soc. 15, 560 (1970).

"Muonic Interactions in  $^{66}\text{Zn}$  and  $^{68}\text{Zn}$ ," Jenkins, Powers and Kunselman, Bull. Am. Phys. Soc. 15, 560 (1970).

"Nuclear Isomer Shifts in  $^{207}\text{Pb}$ ," Jenkins, Powers, Martin, Miller, and Welsh, Bull. Am. Phys. Soc. 15, 1357 (1970).

"Forbidden Transitions in Muonic  $^{208}\text{Pb}$ ," Powers, Jenkins, Martin, Miller and Welsh, Bull. Am. Phys. Soc. 15, 1375 (1970).

"Muonic X-Ray Energy Measurement with the K-Absorption Edge Technique," Jenkins, Powers, Welsh and Kunselman, Bull. Am. Phys. Soc. 16, 126 (1971).

"Nuclear Polarization Measurements in High Z Spherical Nuclei Using Muonic X Rays," Martin, Miller, Welsh, Jenkins and Powers, Bull. Am. Phys. Soc. 16, 126 (1971).

"Nuclear Charge Parameters for  $^{138}\text{Ba}$  Using Muonic X Rays," Martin, Miller, Welsh, Jenkins and Powers, Bull. Am. Phys. Soc. 16, 617 (1971).

"Muonic X Rays in  $^{197}\text{Au}$ ," Powers, Hart, Jenkins, Martin, Miller and Welsh, Bull. Am. Phys. Soc. 16, 617 (1971).

" $\pi$  Mesic Atoms - Experimental Aspects," D. A. Jenkins, invited talk presented at the International Seminar on  $\pi$  - Meson - Nucleus Interactions at Strasbourg, France.

"A Study of Neutron Distributions with Pionic Atoms," D. A. Jenkins, invited talk, Bull. Am. Phys. Soc. 17, 34 (1972).

"Elastic Scattering of  $\pi^-$  from  $\text{O}^{16}$  in the Region of the (3,3) Resonance," J. S. Vincent, R. W. Bercaw, E. T. Boschitz, M. Blecher, K. Gotow, R. C. Minehart, K. Ziock, R. Kerns, R. Johnson, Bulletin of American Physical Society 16, 132 (1971).

"Search for the Reaction  $\mu^- \text{Cu} \rightarrow e^+ \text{Co}$ ," D. Bryman, M. Blecher, K. Gotow, and R. J. Powers, Bulletin of Amer. Phys. Soc. 17, 470 (1972). Talk Presented at 1972 Washington, D. C. meeting by M. Blecher.

Technical Reports:

"Geometry of the Internally Produced Beams in SREL Synchrocyclotron," M. A. Ijaz and K. Gotow, Virginia Polytechnic Institute, HEP-101, December (1965).

"Polarized Proton Beam Produced by SREL Synchrocyclotron," M. A. Ijaz, K. Gotow, B. MacDonald, T. R. Witten and D. A. Wallio, Virginia Polytechnic Institute, HEP-102, November (1966).

"Interaction of Intermediate Energy Protons with Light Nuclei," W. K. Roberts, J. S. Vincent, E. T. Boschitz, K. Gotow, M. Blecher, P. C. Gugelot, C. F. Perdrisat, L. W. Swenson, and J. R. Priest. NASA Technical Note NASA TN D-5961.